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(71) Applicant: MINNESOTA MINING AND MANUFACTURING COMPANY [US/US]; 3M Center, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).

(72) Inventors: BROWN, Omar, D.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). MAIER, Gary, W.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US).

(74) Agents: LEVINE, Charles, D. et al.; Minnesota Mining and Manufacturing Company, Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).

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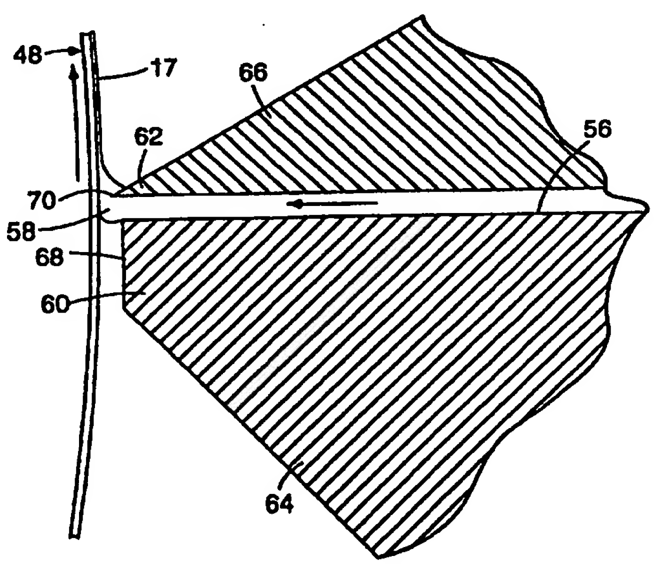

(57) Abstract

A die coating method and apparatus includes a die (40) having an upstream bar (64) with an upstream lip (60) and a downstream bar (66) with a downstream lip (62). The upstream lip (60) is formed as a land (68) and the downstream lip (62) is formed as a sharp edge (70). The shape of the land conforms to the shape of the surface being coated. Changing at least one of the slot height H, the overbite O, and the convergence C can improve coating performance. A replaceable, flexible strip (350) can be used above the coating slot to facilitate replacement of a damaged overbite edge. A low surface energy coating can be applied to the downstream bar and land surfaces.

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DIE COATING METHOD AND APPARATUS

TECHNICAL FIELD

The present invention relates to coating methods. More particularly, the present invention relates to coating methods using a die.

BACKGROUND OF THE INVENTION

U.S. Patent No. 2,681,294 discloses a vacuum method for stabilizing the coating bead for direct extrusion and slide types of metered coating systems. Such stabilization enhances the coating capability of these systems. However, these coating systems lack sufficient overall capability to provide the thin wet layers, even at very low liquid viscosities, required for some coated products.

U.S. Patent No. 2,761,791 teaches using various forms of extrusion and slide coaters to bead--coat multiple liquids simultaneously in a distinct layer relationship onto a moving web. However, these coating systems lack sufficient overall performance to maintain the desired multiple wet layer thickness at the needed web speeds and coating gaps, for some coated products. U.S. Patent No. 5,256,357 discloses a multiple layer coating die with an underbite in one of the slot edges. Underbite in one of the two edges improves the coating situation in some cases.

U.S. Patent No. 4,445,458 discloses an extrusion type bead-coating die with a beveled draw-down surface to impose a boundary force on the downstream side of the coating bead and to reduce the amount of vacuum necessary to maintain the bead. Reduction of the vacuum minimizes chatter defects and coating streaks. To improve coating quality, the obtuse angle of the beveled surface with respect to

the slot axis, and the position along the slot axis of the bevel toward the moving web (overhang) and away from the moving web (underhang) must be optimized. The optimization results in the high quality needed for coating photosensitive emulsions. However, the thin-layer performance capability needed for some coated products is lacking.

U.S. Patent No. 3,413,143 discloses a two slot die with excess coating liquid pumped into the coating bead area through the upstream slot. Approximately half of the entering liquid is pumped out of the bead area through the downstream slot and the remainder is applied to the moving web. The excess liquid in the bead has a stabilizing effect, which improves performance without using a vacuum chamber. However, this apparatus does not provide the performance needed for some coated products, with a maximum stated gap-to-wet-thickness ratio of only 3.

U.S. Patent No. 4,443,504 discloses a slide coating apparatus in which the angle between the slide surface and a horizontal datum plane ranges from 35° to 50° and the takeoff angle defined between a tangent to the coating roll and the slide surface ranges from 85° to 100°. Operation within these ranges provides a compromise between performance from high fluid momentum down the slide and coating uniformity from high liquid leveling force against the slide surface. However, even with a vacuum chamber, this system does not provide the performance needed for some coated products.

A common problem encountered with extrusion die coaters has been the occurrence of streaks in the coated layer, caused by dried liquid residue on the die lips near the coating bead. This is especially true for low-viscosity liquids, containing a highly-

volatile solvent. One solution to this problem, described in PCT Patent Application No. WO 93/14878 involves placing fluorine-containing resin coverings on the die faces adjacent to the lip faces to prevent wetting of these surfaces by coating liquid. This reduces streaking, dripping, and edge waviness. However, the coverings extend to the bead lip edges, and result in non-precision mechanical alignment components which are easily damaged.

European Patent Application No. EP 552653 describes covering a slide coating die surface adjacent to and below the coating bead with a low energy fluorinated polyethylene surface. The covering starts 0.05-5.00 mm below the coating lip tip and extends away from the coating bead. The low-surface-energy covering is separated from the coating lip tip by a bare metal strip. This locates the bead static contact line. The low energy covering eliminates coating streaks and facilitates die cleanup. No mention is made of using this with an extrusion coating die.

Figure 1 shows a known coating die 10 with a vacuum chamber 12 as part of a metered coating system. A coating liquid 14 is precisely supplied by a pump 16 to the die 10 for application to a moving web 18, supported by a backup roller 20. Coating liquid is supplied through a channel 22 to a manifold 24 for distribution through a slot 26 in the die and coating onto the moving web 18. As shown in Figure 2, the coating liquid passes through the slot 26 and forms a continuous coating bead 28 between the upstream die lip 30 and the downstream die lip 32, and the web 18. Dimensions f_1 and f_2, the width of the lips 30, 32 commonly range from 0.25 to 0.76 mm. The vacuum chamber 12 applies a vacuum upstream of the bead to stabilize the bead. While this configuration works

adequately in many situations, there is a need for a die coating method which improves the performance of known methods.

SUMMARY OF THE INVENTION

The present invention is a system for die coating fluid onto a surface. The apparatus includes a die having an upstream bar with an upstream lip and a downstream bar with a downstream lip. The upstream lip is formed as a land and the downstream lip is formed as a sharp edge. A passageway runs through the die between the upstream and downstream bars. The passageway includes a slot defined by the upstream and downstream lips such that coating fluid exits the die from the slot to form a continuous coating bead between the upstream die lip, the downstream die lip, and the surface being coated.

Changing at least one of the slot height, the overbite, and the convergence can improve coating performance. The slot height, the overbite, and the convergence are selected in combination with each other and the length of the land, the edge angle of the downstream bar, the die attack angle between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the sharp edge, and the coating gap distance between the sharp edge and the surface to be coated are selected in combination with each other.

The shape of the land conforms to the shape of the surface being coated. Where the surface is curved, the land is curved. The die also can include applying a vacuum upstream of the bead to stabilize the bead. The vacuum can be applied using a vacuum chamber having a vacuum bar with a land. The shape of the vacuum land also conforms to the shape of the

surface being coated. The land and the vacuum land can have the same radius of curvature and can have the same or different convergences with respect to the surface to be coated.

A replaceable, flexible strip can be clamped between two downstream bars above the coating slot to facilitate replacement of a damaged overbite edge. The strip can be held in position by vacuum applied through the downstream bar.

A low surface energy covering can be applied to the surface of the downstream bar adjacent to the sharp edge, and to the surface of the land, adjacent to its downstream edge. This presents a generally undulating surface. The low surface energy coverings need not extend completely to the edges of the downstream bar and the land. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased.

The method of die coating according to this invention includes passing coating fluid through a slot; improving coating performance by changing at least one of the relative orientations of the land and the sharp edge; selecting the length of the land, the edge angle of the downstream bar, the die attack angle between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the sharp edge, and the coating gap distance between the sharp edge and the surface to be coated in combination with each other; and selecting the slot height, the overbite, and the convergence in combination with each other. The method can also include the step of applying a vacuum upstream of the bead to stabilize the bead.

In another embodiment, the die can have an upstream bar with an upstream lip, a middle bar with a

middle lip, and a downstream bar with a downstream lip. The upstream lip is formed as a land, the middle lip is formed as a sharp edge, and the downstream lip is formed as a sharp edge. A first passageway runs through the die between the upstream and middle bars. The passageway has a first slot defined by the upstream and middle lips, and coating fluid exits the die from the first slot to form a continuous coating bead between the upstream die lip, the middle die lip, and the surface being coated. A second passageway runs through the die between the middle and downstream bars and has a second slot defined by the middle and downstream lips. A predetermined amount of coating fluid leaves the bead and reenters the die in the second slot, and the remaining coating fluid in the bead is coated on the surface to be coated. The bead does not significantly move into the space between the land and the surface to be coated even as vacuum is increased.

The method of die coating according to this embodiment includes passing coating fluid through a first slot; exiting the coating fluid from the first slot to form a continuous coating bead between an upstream die lip, a middle die lip, and the surface being coated; passing a predetermined amount of coating fluid from the bead through a second slot; and coating the remaining coating fluid in the bead on the surface to be coated.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic, cross-sectional view of a known coating die.

Figure 2 is an enlarged cross-sectional view of the slot and lip of the die of Figure 1.

Figure 3 is a cross-sectional view of an extrusion die of the present invention.

Figure 4 is an enlarged cross-sectional view of the slot and lip of the die of Figure 3.

Figure 5 is a cross-sectional view of the slot and lip similar to that of Figure 4.

Figure 6 is a cross-sectional view of an alternative vacuum chamber arrangement.

Figure 7 is a cross-sectional view of another alternative vacuum chamber arrangement.

Figure 8 is a cross-sectional view of an alternative extrusion die of the present invention.

Figures 9a and 9b are enlarged cross-sectional views of the slot, face, and vacuum chamber of the die of Figure 8.

Figures 10a and 10b are schematic views of the die of Figure 8.

Figure 11 shows coating test results which compare the performance of a known extrusion die and an extrusion die of the present invention for a coating liquid of 1.8 centipoise viscosity.

Figure 12 shows comparative test results for a coating liquid of 2.7 centipoise viscosity.

Figure 13 is a collection of data from coating tests.

Figure 14 is a graph of constant G/Tw lines for an extrusion coating die of the present invention for nine different coating liquids.

Figure 15 is a cross-sectional view of a flexible lip strip.

Figure 16 is a cross-sectional view of a film strip is held in position by a light vacuum applied through the downstream bar.

Figure 17 is a cross-sectional view of the face of an extrusion die of the present invention having low surface energy coverings.

Figure 18 is an enlarged cross-sectional view of a face of an extrusion die of the present invention, similar to that of Figure 17.

Figure 19 is a schematic, cross-sectional view of another embodiment of the present invention.

Figure 20 is an enlarged cross-sectional view of the die face and coating bead of the die of Figure 19.

DETAILED DESCRIPTION

This invention is a die coating method and apparatus where the die includes a sharp edge and a land which are positioned to improve and optimize performance. The land is configured to match the shape of the surface in the immediate area of coating liquid application. The land can be curved to match a web passing around a backup roller or the land can be flat to match a free span of web between rollers.

Figure 3 shows the extrusion die 40 with a vacuum chamber 42 of the present invention. Coating liquid 14 is supplied by a pump 46 to the die 40 for application to a moving web 48, supported by a backup roller 50. Coating liquid is supplied through a channel 52 to a manifold 54 for distribution through a slot 56 and coating onto the moving web 48. As shown in Figure 4, the coating liquid 14 passes through the slot 56 and forms a continuous coating bead 58 among the upstream die lip 60, the downstream die lip 62, and the web 48. The coating liquid can be one of numerous liquids or other fluids. The upstream die lip 60 is part of an upstream bar 64, and the downstream die 62 lip is part of a downstream bar 66. The height of the slot 56 can be controlled by a U-shaped shim which can be made of brass or stainless steel and which can be deckled. The vacuum chamber 42

applies vacuum upstream of the bead to stabilize the coating bead.

As shown in Figure 5, the upstream lip 60 is formed as a curved land 68 and the downstream lip 62 is formed as a sharp edge 70. This configuration improves overall performance over that of known die-type coaters. Improved performance means permitting operating at increased web speeds and increased coating gaps, operating with higher coating liquid viscosities, and creating thinner wet coating layer thicknesses.

The sharp edge 70 should be clean and free of nicks and burrs, and should be straight within 1 micron in 25 cm of length. The edge radius should be no greater than 10 microns. The edge can be formed of an acute angle, as shown or as a right or obtuse angle, with or without a bevel. Alternatively, the edge can be formed with a "drop nose", on an extension of the downstream lip 62 that narrows the slot 56. Regardless of the edge configuration, proper overbite is required to maintain performance. The radius of the curved land 68 should be equal to the radius of the backup roller 50 plus a minimal, and non-critical, 0.13 mm allowance for coating gap and web thickness. Alternatively, the radius of the curved land 68 can exceed that of the backup roller 50 and shims can be used to orient the land with respect to the web 48. A given convergence C achieved by a land with the same radius as the backup roller can be closely approached by a land with a larger radius than the backup roller by manipulating the land with the shims.

Figure 5 also shows dimensions of geometric operating parameters for single layer extrusion. The length L_1 of the curved land 68 on the upstream bar 64 can range from 1.6 mm to 25.4 mm. The preferred length L_1 is 12.7 mm. The edge angle A_1 of the

downstream bar 66 can range from 10° to 75°, and is preferably 60°. The edge radius of the sharp edge 70 should be from about 2 microns to about 4 microns and preferably less than 10 microns. The die attack angle A_2 between the downstream bar 66 surface of the coating slot 56 and the tangent plane P through a line on the web 48 surface parallel to, and directly opposite, the sharp edge 70 can range from 30° to 150° and is preferably 90°-95°, such as 93°. The coating gap G_1 is the perpendicular distance between the sharp edge 70 and the web 48. (The coating gap G_1 is measured at the sharp edge but is shown in some Figures spaced from the sharp edge for drawing clarity. Regardless of the location of G_1 in the drawings - and due to the curvature of the web the gap increases as one moves away from the sharp edge - the gap is measured at the sharp edge.)

Slot height H can range from 0.076 mm to 3.175 mm. Overbite O is a positioning of the sharp edge 70 of the downstream bar 66, with respect to the downstream edge 72 of the curved land 68 on the upstream bar 64, in a direction toward the web 48. Overbite also can be viewed as a retraction of the downstream edge 72 of the curved land 68 away from the web 48, with respect to the sharp edge 70, for any given coating gap G_1. Overbite can range from 0 mm to 0.1.02 mm, and the settings at opposite ends of the die slot should be within 2.5 microns of each other. A precision mounting system for this coating system is required, for example to accomplish precise overbite uniformity. Convergence C is a counterclockwise, as shown in Figure 5, angular positioning of the curved land 68 away from a location parallel to (or concentric with) the web 48, with the downstream edge 72 being the center of rotation. Convergence can

range from 0° to 4.58°, and the settings at opposite ends of the die slot should be within 0.023° of each other. The slot height, overbite, and convergence, as well as the fluid properties such as viscosity affect the performance of the die coating apparatus and method.

From an overall performance standpoint, for liquids within the viscosity range of 1,000 centipoise and below, it is preferred that the slot height be 0.18 mm, the overbite be 0.076 mm, and the convergence be 0.57°. Performance levels using other slot heights can be nearly the same. Performance advantages can also be found at viscosities above 1,000 centipoise. Holding convergence at 0.57°, some other optimum slot height and overbite combinations are as follows:

Slot Height	Overbite
0.15 mm	0.071 mm
0.20 mm	0.082 mm
0.31 mm	0.100 mm
0.51 mm	0.130 mm

In the liquid viscosity range noted above, and for any given convergence value, the optimum overbite value appears to be directly proportional to the square root of the slot height value.

As shown in Figure 6, the vacuum chamber 42 can be an integral part of, or clamped to, the upstream bar 64 to allow precise, repeatable vacuum system gas flow. The vacuum chamber 42 is formed using a vacuum bar 74 and can be connected through an optional vacuum restrictor 76 and a vacuum manifold 78 to a vacuum source channel 80. A curved vacuum land 82 can be an integral part of the upstream bar 64, or can be part of the vacuum bar 74, which is secured to the upstream bar 64. The vacuum land 82 has the same radius of curvature as the curved land 68. The curved

land 68 and the vacuum land 82 can be finish-ground together so they are "in line" with each other. The vacuum land 82 and the curved land 68 then have the same convergence C with respect to the web 48.

The vacuum land gap G_2 is the distance between the vacuum land 82 and the web 48 at the lower edge of the vacuum land and is the sum total of the coating gap G_1, the overbite O, and the displacement caused by convergence C of the curved land 68. (Regardless of the location of G_1 in the drawings the gap is the perpendicular distance between the lower edge of the vacuum land and the web.) When the vacuum land gap G_2 is large, an excessive inrush of ambient air to the vacuum chamber 42 occurs. Even though the vacuum source may have sufficient capacity to compensate and maintain the specified vacuum pressure level at the vacuum chamber 42, the inrush of air can degrade coating performance.

In Figure 7, the vacuum land 82 is part of a vacuum bar 74 which is attached to the upstream bar 64. During fabrication, the curved land 68 is finished with the convergence C "ground in." The vacuum bar 74 is then attached and the vacuum land 82 is finish ground, using a different grind center, such that the vacuum land 82 is parallel to the web 48, and the vacuum land gap G_2 is equal to the coating gap G_1 when the desired overbite value is set. The vacuum land length L_2 may range from 6.35 mm to 25.4 mm. The preferred length L_2 is 12.7 mm. This embodiment has greater overall coating performance capability in difficult coating situations than the embodiment of Figure 6, but it is always finish ground for one specific set of operating conditions. So, as coating gap G_1 or overbite O are changed vacuum land gap G_2 may move away from its optimum value.

In Figures 8 and 9 the upstream bar 64 of the die 40 is mounted on an upstream bar positioner 84, and the vacuum bar 74 is mounted on a vacuum bar positioner 86. The curved land 68 on the upstream bar 64 and the vacuum land 82 on the vacuum bar 74 are not connected directly to each other. The vacuum chamber 42 is connected to its vacuum source through the vacuum bar 74 and the positioner 86. The mounting and positioning for the vacuum bar 74 are separate from those for the upstream bar 64. This improves performance of the die and allows precise, repeatable vacuum system gas flow. The robust configuration of the vacuum bar system also aids in the improved performance as compared with known systems. Also, this configuration for the vacuum bar 74 could improve performance of other known coaters, such as slot, extrusion, and slide coaters. A flexible vacuum seal strip 88 seals between the upstream bar 64 and the vacuum bar 74.

The gap G_2 between the vacuum land 82 and the web 48 is not affected by coating gap G_1, overbite O, or convergence C changes, and may be held at its optimum value continuously, during coating. The vacuum land gap G_2 may be set within the range from 0.076 mm to 0.508 mm. The preferred value for the gap G_2 is 0.15 mm. The preferred angular position for the vacuum land 82 is parallel to the web 48.

During coating, the vacuum level is adjusted to produce the best quality coated layer. A typical vacuum level, when coating a 2 centipoise coating liquid at 6 microns wet layer thickness and 30.5 m/min web speed, is 51 mm H_2O. Decreasing wet layer thickness, increasing viscosity, or increasing web speed could require higher vacuum levels exceeding 150 mm H_2O. Dies of this invention exhibit lower satisfactory minimum vacuum levels and higher

satisfactory maximum vacuum levels than known systems, and in some situations can operate with zero vacuum where known systems cannot.

Figures 10a and 10b show some positioning adjustments and the vacuum chamber closure. Overbite adjustment translates the downstream bar 66 with respect to the upstream bar 64 such that the sharp edge 70 moves toward or away from the web 48 with respect to the downstream edge 72 of the curved land 68. Adjusting convergence rotates the upstream bar 64 and the downstream bar 66 together around an axis running through the downstream edge 72, such that the curved land 68 moves from the position shown in Figure 10, away from parallel to the web 48, or back toward parallel. Coating gap adjustment translates the upstream bar 64 and the downstream bar 66 together to change the distance between the sharp edge 70 and the web 48, while the vacuum bar remains stationary on its mount 86, and the vacuum seal strip 88 flexes to prevent air leakage during adjustments. Air leakage at the ends of the die into the vacuum chamber 42 is minimized by end plates 90 attached to the ends of the vacuum bar 74 which overlap the ends of the upstream bar 64. The vacuum bar 74 is 0.10 mm to 0.15 mm longer than the upstream bar 64, so, in a centered condition, the clearance between each end plate 90 and the upstream bar 64 will range from 0.050 mm to 0.075 mm.

One unexpected operating characteristic has been observed during coating. The bead does not move significantly into the space between the curved land 68 and the moving web 48, even as vacuum is increased. This allows using higher vacuum levels than is possible with known extrusion coaters, and provides a correspondingly higher performance level. Even where little or no vacuum is required, the invention

exhibits improved performance over known systems. That the bead does not move significantly into the space between the curved land 68 and the web 48 also means that the effect of "runout" in the backup roller 50 on downstream coating weight does not differ from that for known extrusion coaters.

Figure 11 graphs results of coating tests which compare the performance of a known extrusion die with an extrusion die of this invention. In the tests, the 1.8 centipoise coating liquid containing an organic solvent was applied to a plain polyester film web. The performance criterion was minimum wet layer thickness at four different coating gap levels for each of the two coating systems, over the speed range of 15 to 60 m/min. Curves A, B, C, and D use the known, prior art die and were performed with coating gaps of 0.254 mm, 0.203 mm, 0.152 mm, and 0.127 mm, respectively. Curves E, F, G, and H use a die according to this invention at the same respective coating gaps. The lower wet thickness levels for this invention, compared to the prior art die, are easily visible. Figure 12 shows comparative test results for a similar coating liquid of 2.7 centipoise viscosity, at the same coating gaps. Once again, the performance advantage for this invention is clearly visible.

Figure 13 is a collection of data from coating tests where liquids at seven different viscosities, and containing different organic solvents, were applied to plain polyester film webs. The results compare performance of the prior art extrusion coater (PRIOR) and this invention (NEW). The performance criteria are mixed. Performance advantages for this invention can be found in web speed (Vw), wet layer thickness (Tw), coating gap, vacuum level, or a combination of these.

One measure of coater performance is the ratio of coating gap to wet layer thickness (G/Tw), for a particular coating liquid and web speed. Figure 14 shows a series of constant G/Tw lines and viscosity values of an extrusion die of this invention, for nine different coating liquids. The liquids were coated on plain polyester film base at a web speed of 30.5 m/min. A few viscosity values appear to be out of order, due to the effect of other coatability factors. Four additional performance lines have been added after calculating the G/Tw values for 30.5 m/min web speed from Figures 11 and 12. From top to bottom, the solid performance lines are the G/Tw for liquids of 2.7 centipoise and 1.8 centipoise coated by a known extrusion die and the G/Tw for liquids of 2.7 centipoise and 1.8 centipoise coated by an extrusion die of this invention. The lines for of this invention represent greater G/Tw values than the lines for of the prior art coating die. In addition, the lines for this invention are close to being lines of constant G/Tw, averaging 18.8 and 16.8, respectively. The lines of the known coater show considerably more G/Tw variation over their length. This invention has a much improved operating characteristic for maintaining a coating bead at low wet thickness values, over known systems.

To facilitate replacement of a damaged overbite edge, alternatives to a machine-ground edge can be used. Figure 15 shows a replaceable, flexible strip 350 clamped between two downstream bars above the coating slot. The strip can be stainless feeler gauge stock or other metal, or plastic film, and can be used in any embodiment of this invention. A fixture for grinding a sharp edge on stainless feeler gauge stock minimizes edge burr during grinding. Figure 16 shows the strip held in position by a light

vacuum applied through the downstream bar. In another alternative embodiment, a fine stainless wire can be used to create the sharp edge. The wire can be tensioned.

A common problem encountered with known extrusion die coaters is the occurrence of streaks in the coated layer, caused by dried liquid residue on the die lips near the coating bead. This is more prevalent with low viscosity liquids that contain a highly-volatile solvent. In Figure 17, low surface energy coverings 260 are applied to the surface of the downstream bar 66 adjacent to the sharp edge 70, and to the curved land 68 adjacent to its downstream edge 72. This covering, can be a fluorinated polyethylene, and presents a generally undulating surface, even if applied to a precisely-ground metal base material. Best results are obtained if the overbite O is precisely set, side-to-side, on the die within 2.5 microns.

In the embodiment of Figure 18, the low surface energy coverings 260 do not extend to the edges 70 and 72. These coverings 260 can be applied as an inlay 262 formed by cutting a recess in the curved land 68, applying excess low surface energy material to overfill the recess, and then radius-grinding the entire curved land such that the narrow metal strip 264 is flush with the "non-wetting" covering inlay 262. The depth of the inlay 262 can range from 0.013 mm to 0.127 mm. The width of the narrow strip 264 can range from 0.127 mm to 0.762 mm. A similar low surface energy inlay can be produced in the downstream bar 66 surface, starting 0.127 mm - 0.762 mm above the sharp edge 70. With precisely - ground strips 264 adjacent the edges 70 and 72, precise adjustment of overbite is facilitated and the

low surface energy layer is protected from damage and delamination.

Figures 19 and 20 show a system of the present invention for die coating where excess coating liquid is continuously metered into the coating bead from a die 270, and some of the coating liquid is subtractively metered out, such that a specified amount is coated onto the moving web. Coating liquid 14 is supplied to the die 270 by a pump 272, and returned to a sump 274 by a second pump 276. The die 270, using a stabilizing vacuum chamber 278, coats the precisely metered amount of coating liquid onto the web 48 moving over a backup roller 280.

An upstream bar 282, a middle bar 284, and a downstream bar 286 face the web 48. Coating liquid 14 is pumped through an inlet channel 288 into a manifold 290 and through a flow slot 292 into the coating bead. Meanwhile, a predetermined amount of coating liquid is pumped out of the coating bead through an exit slot 294 into an exit manifold 296 and through an exit channel 298. The coating liquid remaining in the bead is coated onto the moving web 48. This system out-performs known systems.

In one example, where the attack angle A_2 between the supply slot 292 and the tangent plane P through the coating bead was 135°, and the attack angle A_5 between the exit slot 294 and the tangent plane P was 115°, the die parameters were set as follows. The supply slot 292 height was 0.15 mm, and its overbite (middle edge 300 compared with the downstream edge 72 of the curved land) was 0.0 mm. The exit slot 294 was 0.076 mm, and its overbite (downstream edge 70 compared with the middle edge 300) was 0.076 mm. The cross-web width of the exit slot 294 was 3.2 mm less than the width of the supply slot 292 to eliminate air

entrainment in the bead. The convergence C was 0.23°. When coating a 2 centipoise liquid at 30.5 m/min web speed, the wet layer thickness Tw was 0.020 mm, and the coating gap G_1 was 0.20 mm (G/Tw=10). In this case, 154% of the required amount of coating liquid was delivered by the supply pump 272, and 35% of the total quantity (removing the entire excess) was extracted by the exit pump 276. When coating at 15.2 m/min web speed, the wet layer thickness Tw was 0.0076 mm, and the coating gap G_1 was 0.20 mm (G/Tw=26.3), and 558% of the required amount of coating liquid was delivered by the supply pump 272, and 82% of the total quantity was extracted by the exit pump 276. The coats were smooth and streak-free.

Alternatively, the attack angle A_2 between the supply slot 292 and the tangent plane P can range from 90° to 135°, and the attack angle A_5 between the exit slot 294 and the tangent plane P can range from 60° to 115°. Also, the vacuum bar can be mounted and adjusted separately from the upstream bar 282.

CLAIMS

1. A die coating apparatus for coating fluid coating onto a surface comprising:

a die 40 having an upstream bar 64 with an upstream lip 60 and a downstream bar 66 with a downstream lip 62, wherein the upstream lip is formed as a land 68 and the downstream lip is formed as a sharp edge 70; and

a passageway running through the die 40 between the upstream and downstream bars 64, 66, wherein the passageway comprises a slot 56 defined by the upstream and downstream lips 60, 62, wherein coating fluid 14 exits the die from the slot to form a continuous coating bead 58 between the upstream die lip, the downstream die lip, and the surface being coated.

2. The die coating apparatus of claim 1 wherein the sharp edge 70 is positioned with respect to a downstream edge of the land 68 to create an overbite O.

3. The die coating apparatus of claim 1 wherein the land 68 is angularly positioned away from a location parallel to or concentric with the web, using the downstream edge of the land as the center of rotation.

4. The die coating apparatus of claim 1 wherein the gap between the sharp edge and the surface is more than ten times the thickness of the coating on the surface.

5. The die coating apparatus of claim 1 further comprising means for improving coating

performance by changing at least one of the slot height H, the overbite O, and the convergence C, wherein the slot height, the overbite, and the convergence are selected in combination with each other and wherein the length L_1 of the land 68, the edge angle A_1 of the downstream bar 66, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the sharp edge 70, and the coating gap distance G between the sharp edge and the surface to be coated are selected in combination with each other.

6. The die coating apparatus of claim 1 wherein the shape of the land 68 conforms to the shape of the surface being coated.

7. The die coating apparatus of claim 1 further comprising means for applying a vacuum upstream of the bead 58 to stabilize the bead comprising a vacuum chamber 42 having a vacuum land 82 as its upstream closure.

8. The die coating apparatus of claim 7 wherein the land 68 and the vacuum land 82 are curved and have the same radius of curvature, wherein the vacuum land is concentric with the land and has the same convergence C with respect to the surface to be coated as does the land, and wherein the vacuum land has zero convergence with respect to the surface to be coated and the land converges at a constant set value with respect to the surface to be coated.

9. The die coating apparatus of claim 1 wherein the downstream lip 62 comprises a replaceable, flexible strip 350.

10. The die coating apparatus of claim 9 wherein the replaceable, flexible strip 350 is held in position above the coating slot by a light vacuum applied through the downstream bar 66.

11. The die coating apparatus of claim 1 wherein the downstream lip 62 comprises a tensioned fine wire.

12. The die coating apparatus of claim 1 further comprising:

a low surface energy covering 260 applied to the surface of the downstream bar 66 adjacent to the sharp edge 70, and a low surface energy covering 260 applied to the land 68, adjacent to its downstream edge to present a generally undulating surface, wherein the low surface energy coverings do not extend completely to the edges of the downstream bar and the land.

13. A method of die coating a fluid coating onto a surface comprising:

passing coating fluid 14 through a slot 56 defined by an upstream bar 64 with an upstream lip 60 and a downstream bar 66 with a downstream lip 62, wherein the upstream lip is formed as a land 68 and the downstream lip is formed as a sharp edge 70; and

selecting the slot height H, the overbite O, and the convergence C in combination with each other.

14. The method of claim 13 further comprising locating the sharp edge a distance from the surface that is more than ten times the thickness of the coating on the surface.

15. The method of claim 13 further comprising selecting the length L_1 of the land 68, the edge angle A_1 of the downstream bar 66, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the sharp edge 70, and the coating gap distance G between the sharp edge and the surface to be coated in combination with each other.

16. The method of claim 13 further comprising the step of applying a vacuum upstream of the bead 58 to stabilize the bead.

17. The method of claim 13 further comprising selecting the shape of the land 68 to conform to the shape of the surface being coated.

18. A die coating apparatus for coating fluid coating onto a surface comprising:

a die 270 having an upstream bar 282 with an upstream lip 60, a middle bar 284 with a middle lip, and a downstream bar 286 with a downstream lip, wherein the upstream lip is formed as a land 68, the middle lip is formed as a sharp edge 300, and the downstream lip is formed as a sharp edge 70; and

a first passageway running through the die between the upstream and middle bars 282, 284, wherein the passageway comprises a first slot 292 defined by the upstream and middle lips, wherein coating fluid 14 exits the die from the first slot to form a continuous coating bead 58 between the upstream die lip, the middle die lip, and the surface being coated, a second passageway running through the die between the middle and downstream bars, wherein the passageway comprises a second slot 294 defined by the middle and downstream

lips, wherein a predetermined amount of coating fluid leaves the bead and reenters the die in the second slot, and the remaining coating fluid in the bead is coated on the surface to be coated.

19. The die of claim 18 wherein the shape of the land 68 conforms to the shape of the surface being coated.

20. The die of claim 18 further comprising means for improving coating performance by changing at least one of the slot heights H, the overbites O, and the convergence C, wherein the slot heights, the overbites, and the convergence are selected in combination with each other and wherein the length of the land L, the edge angle A_1 of the middle and downstream bars, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the downstream lip sharp edge, and the coating gap distance G between the downstream lip sharp edge and the surface to be coated are selected in combination with each other.

21. A method of die coating comprising:

passing coating fluid 14 through a first slot 292 defined by an upstream bar 282 with an upstream lip and a middle bar 284 with a middle lip, wherein the upstream lip is formed as a land 68 and the middle lip is formed as a sharp edge 300;

exiting the coating fluid 14 from the first slot 292 to form a continuous coating bead 58 between the upstream die lip, the middle die lip, and the surface being coated;

passing a predetermined amount of coating fluid 14 from the bead 58 through a second slot 294 defined by the middle bar 284 and a downstream bar 286 with a downstream lip, wherein the downstream lip is formed as a sharp edge 70 to remove the predetermined amount of coating fluid from the bead; and

coating the remaining coating fluid 14 in the bead 58 on the surface to be coated.

22. The method of claim 21 further comprising the steps of:

selecting the length L of the land, the edge angle A_1 of the middle and downstream bars, the die attack angle A_2 between the downstream bar surface of the coating slot and a tangent plane through a line on the surface to be coated parallel to, and directly opposite, the downstream lip sharp edge, and the coating gap distance G between the downstream lip sharp edge and the surface to be coated in combination with each other; and

selecting the slot heights H, the overbites O, and the convergence C in combination with each other.

23. The method of claim 21 wherein the shape of the land 68 conforms to the shape of the surface being coated.

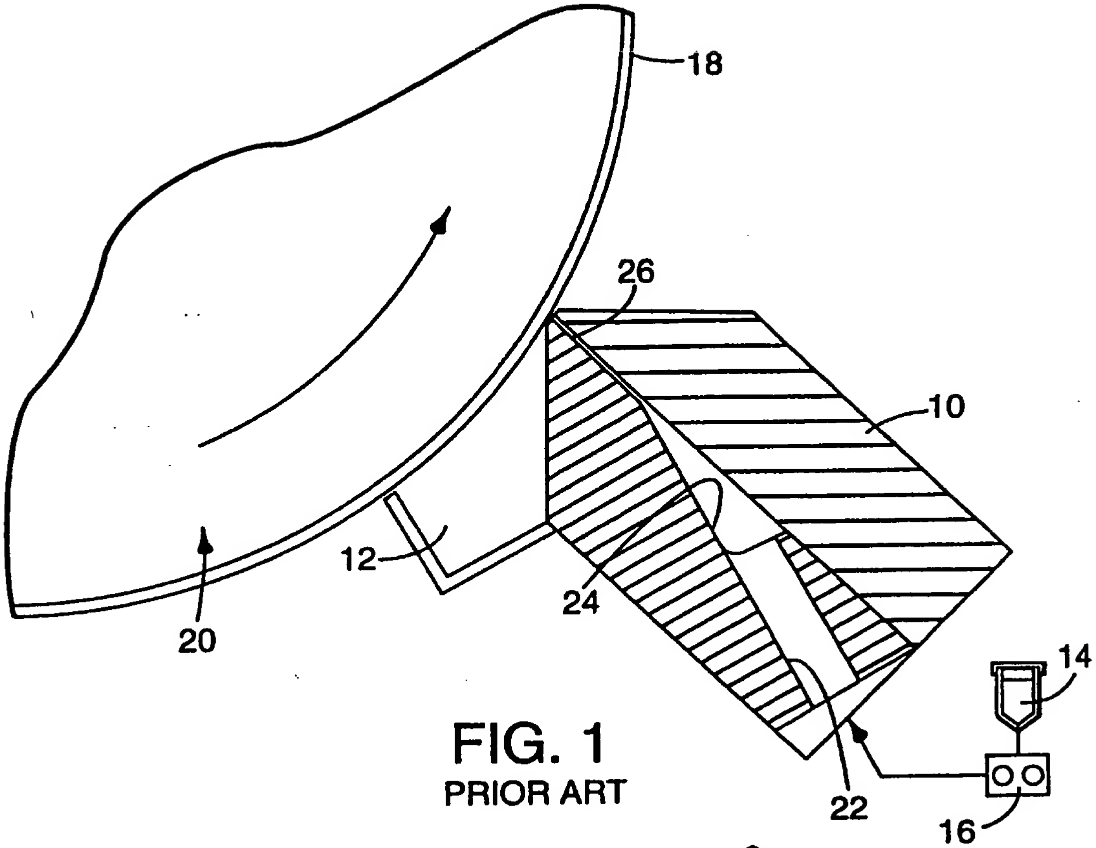

FIG. 1
PRIOR ART

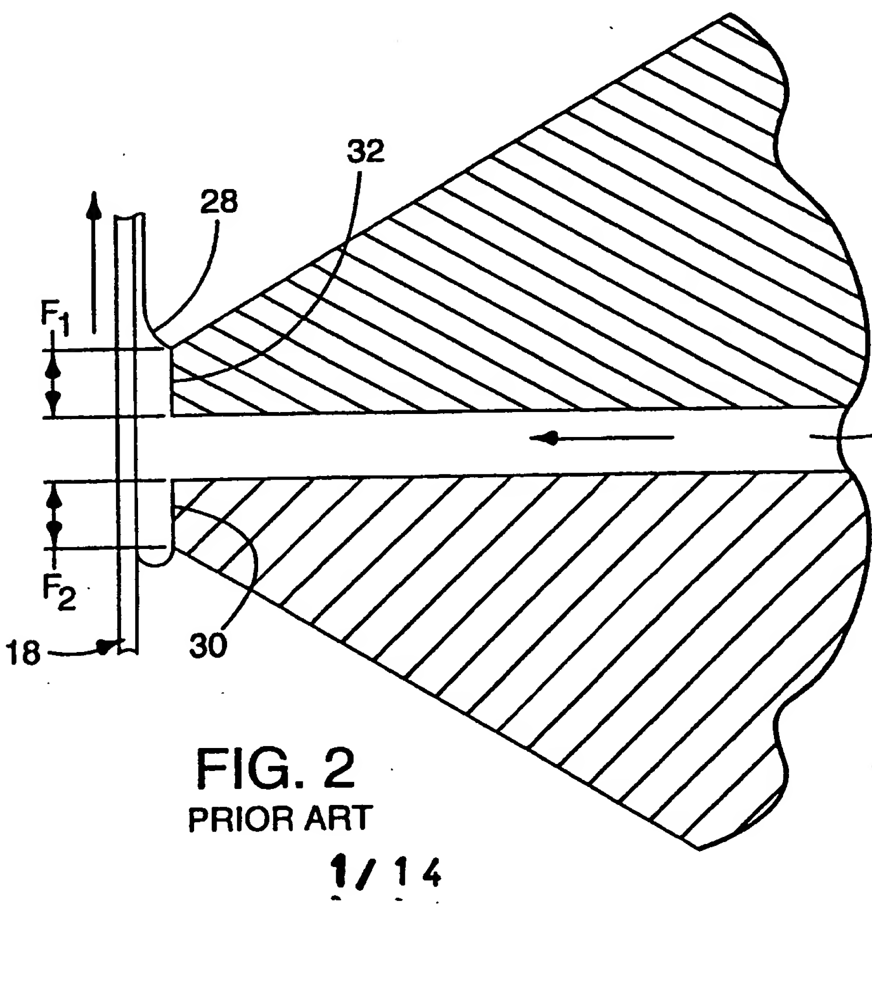

FIG. 2
PRIOR ART

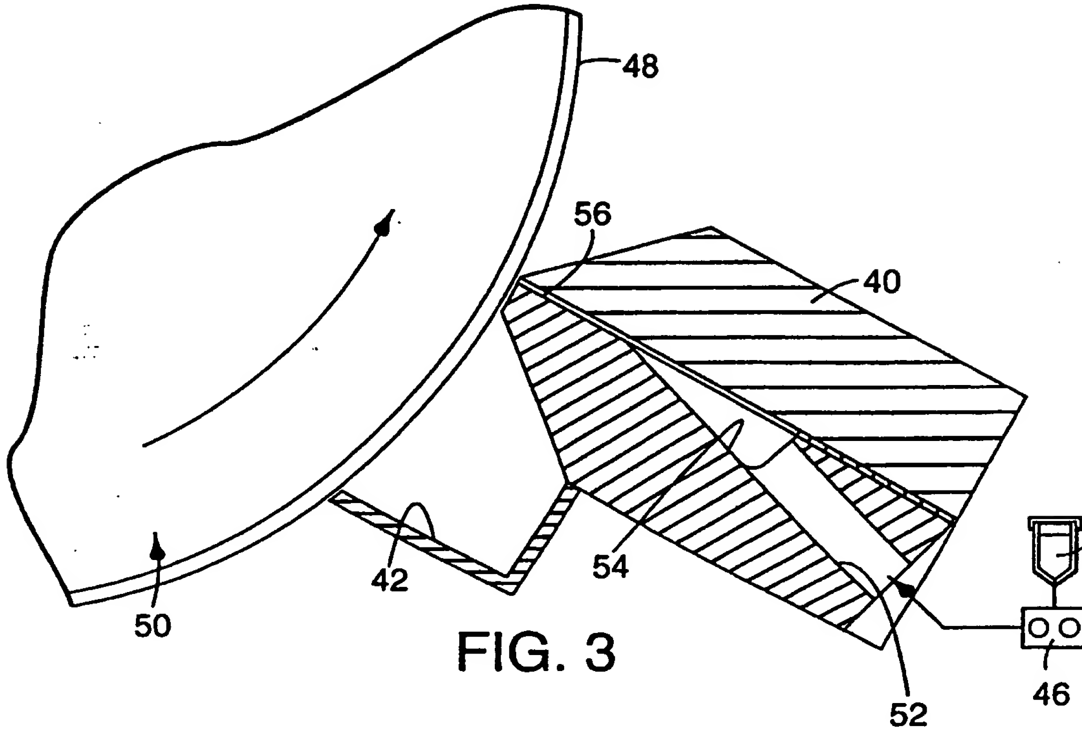

FIG. 3

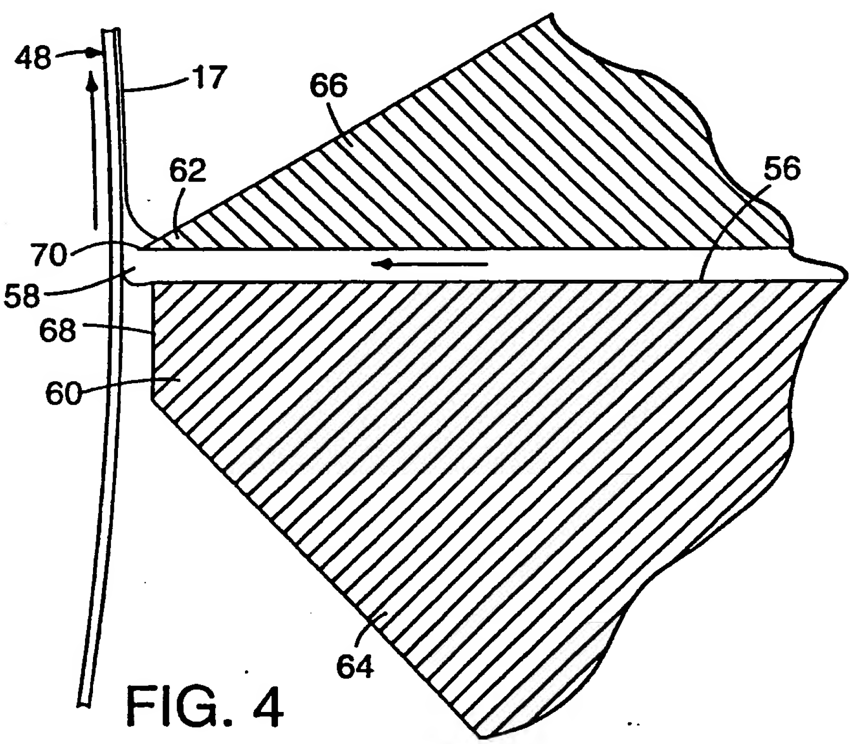

FIG. 4

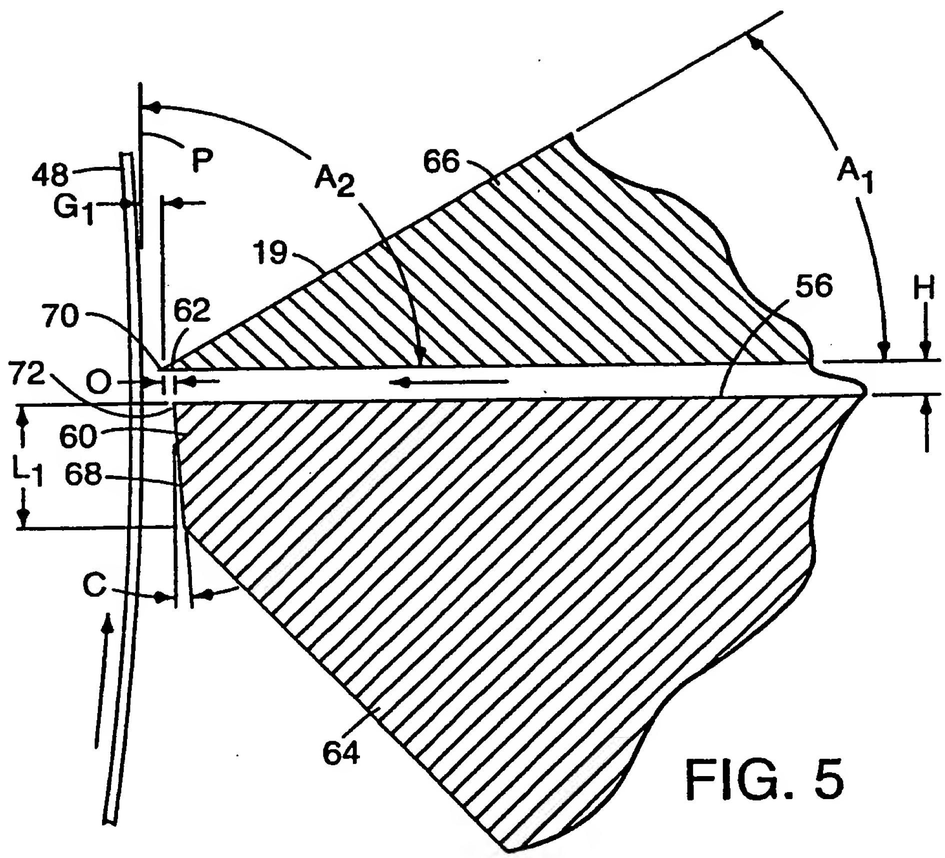

FIG. 5

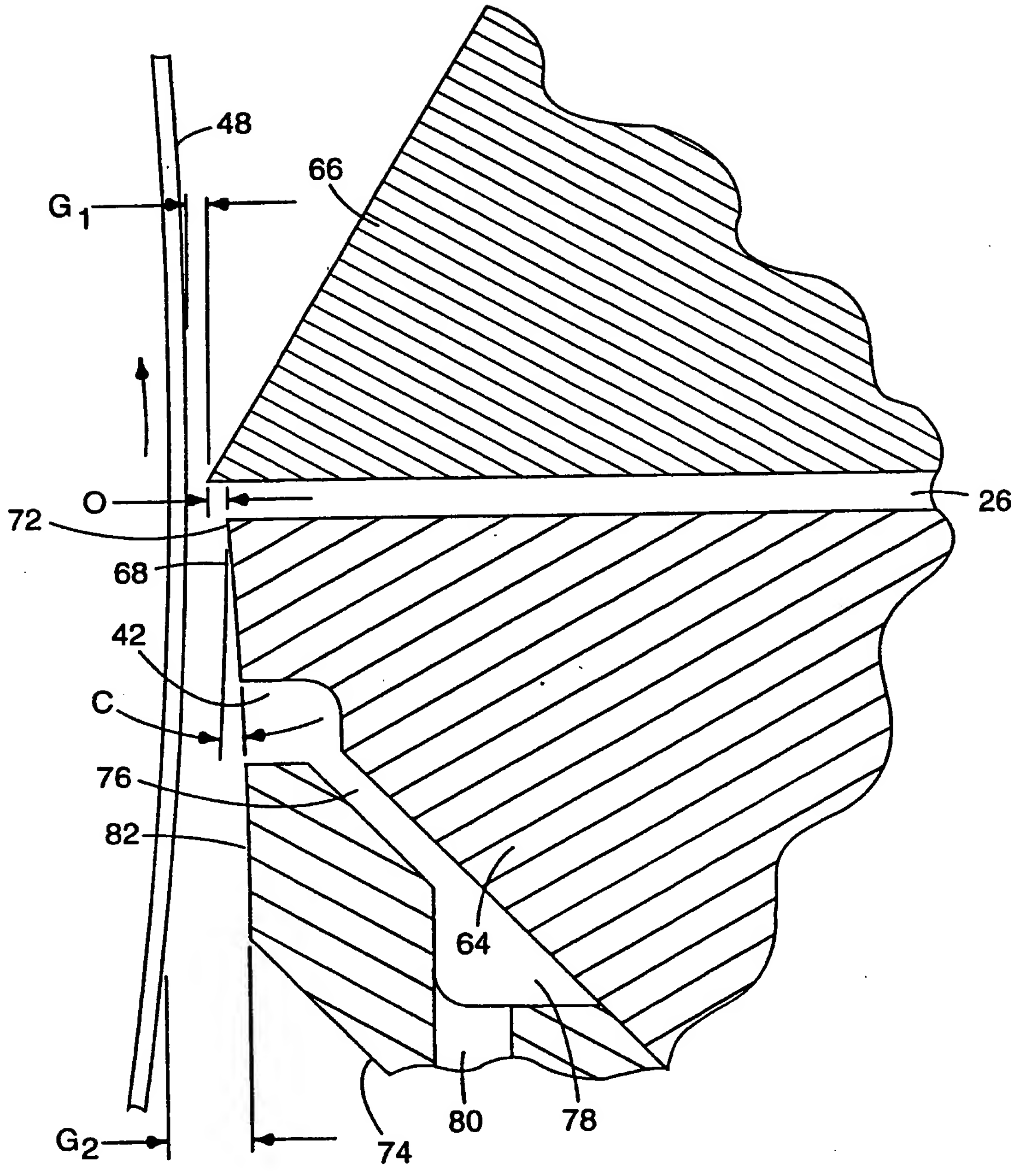

FIG. 6

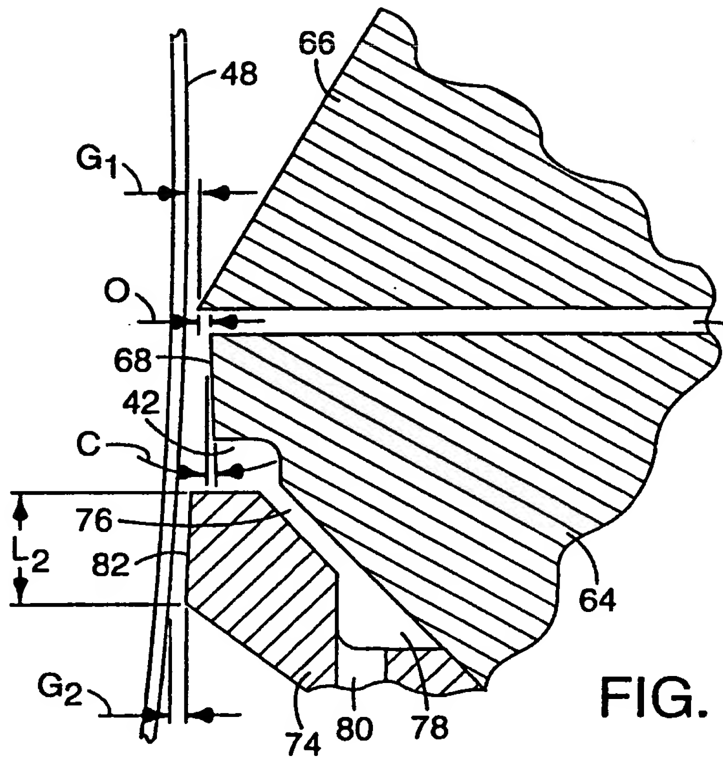
66
48
G_1
O
56
68
42
C
76
L_2
82
64
G_2
74
80
78

FIG. 7

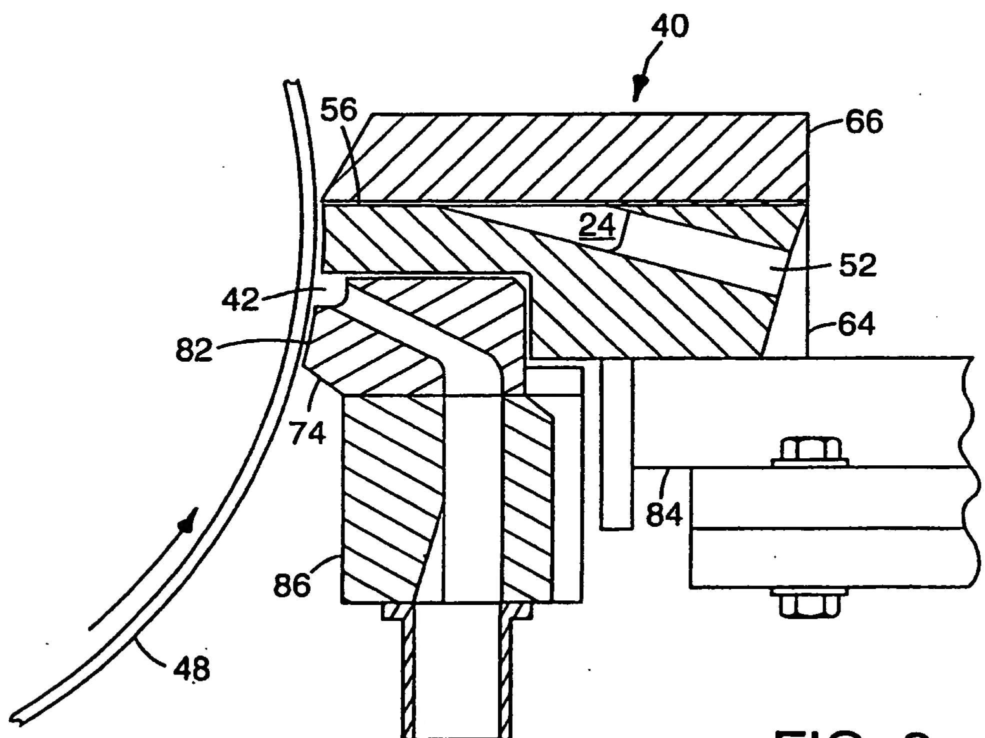
40
56
66
24
52
42
64
82
74
84
86
48

FIG. 8

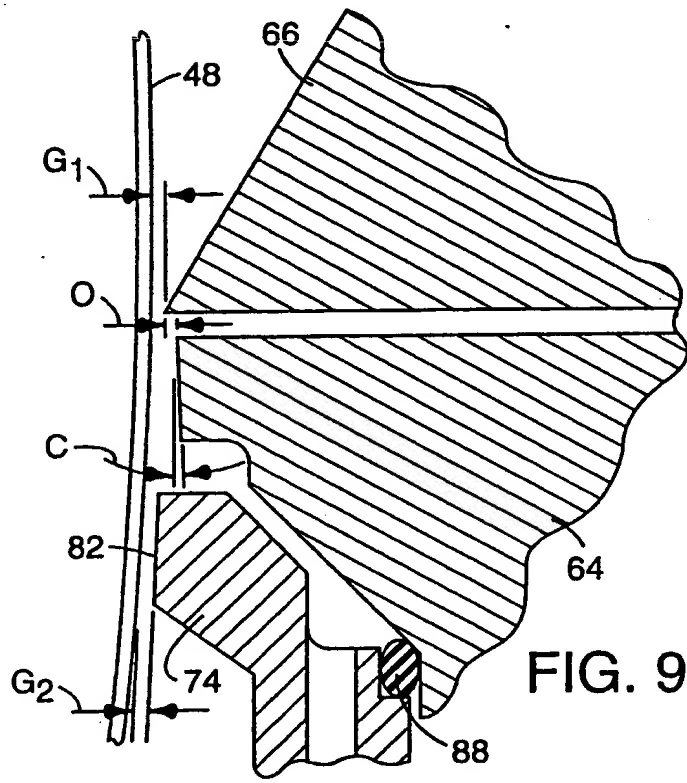

FIG. 9a

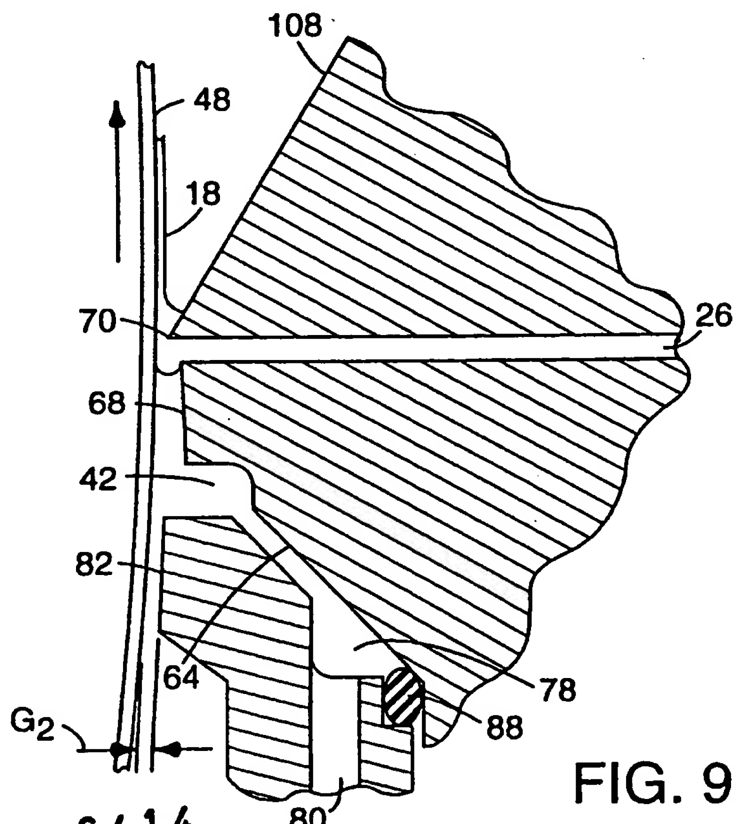

FIG. 9b

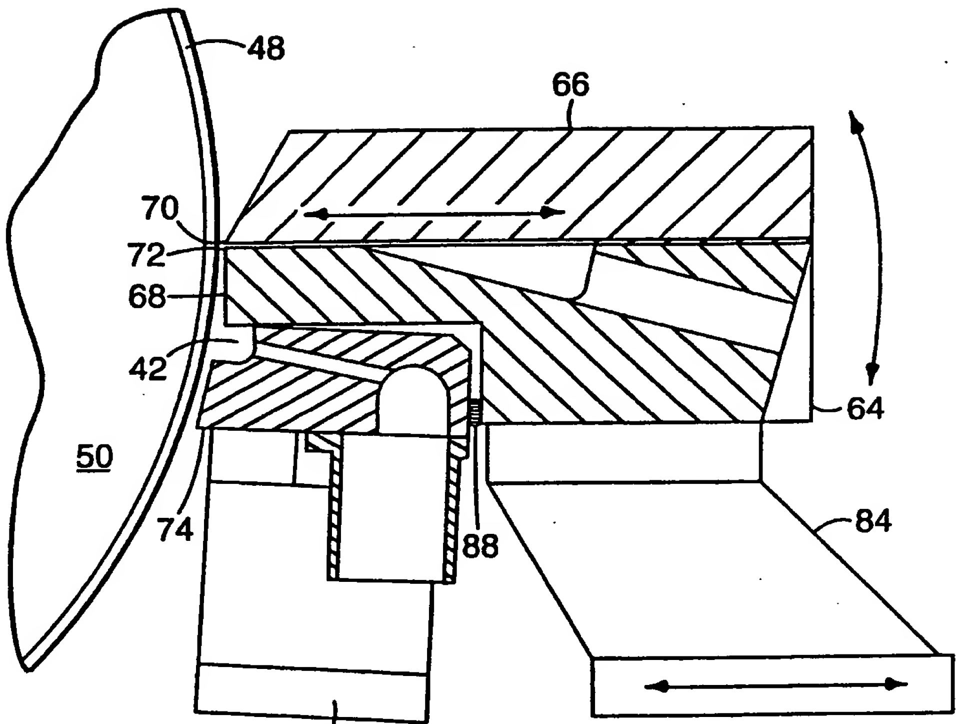

FIG. 10a

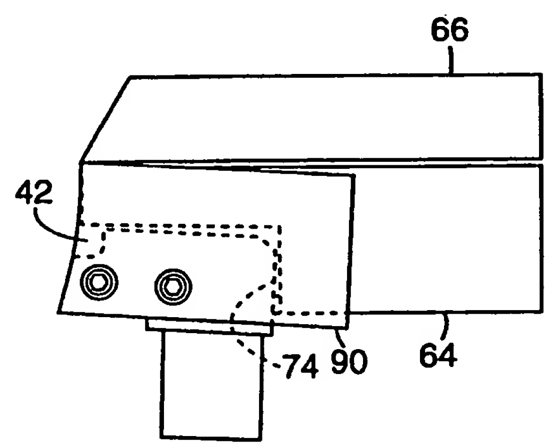

FIG. 10b

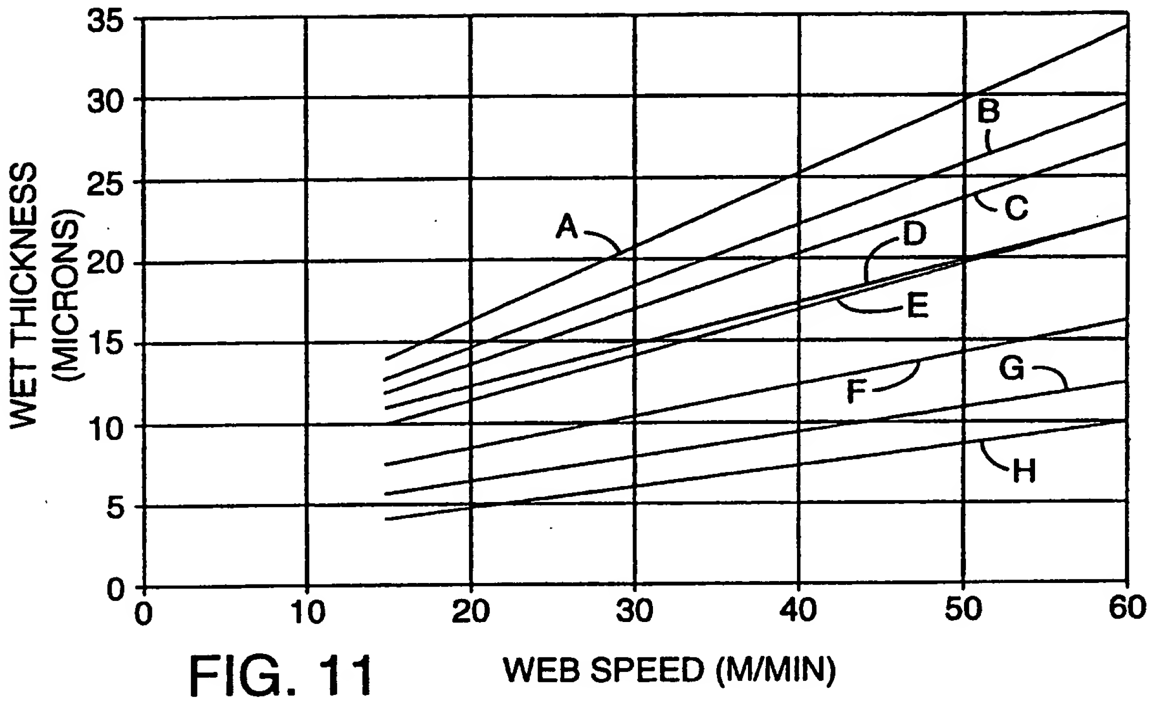
WET THICKNESS (MICRONS)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
A
B
C
D
E
F
G
H
WEB SPEED (M/MIN)

FIG. 11

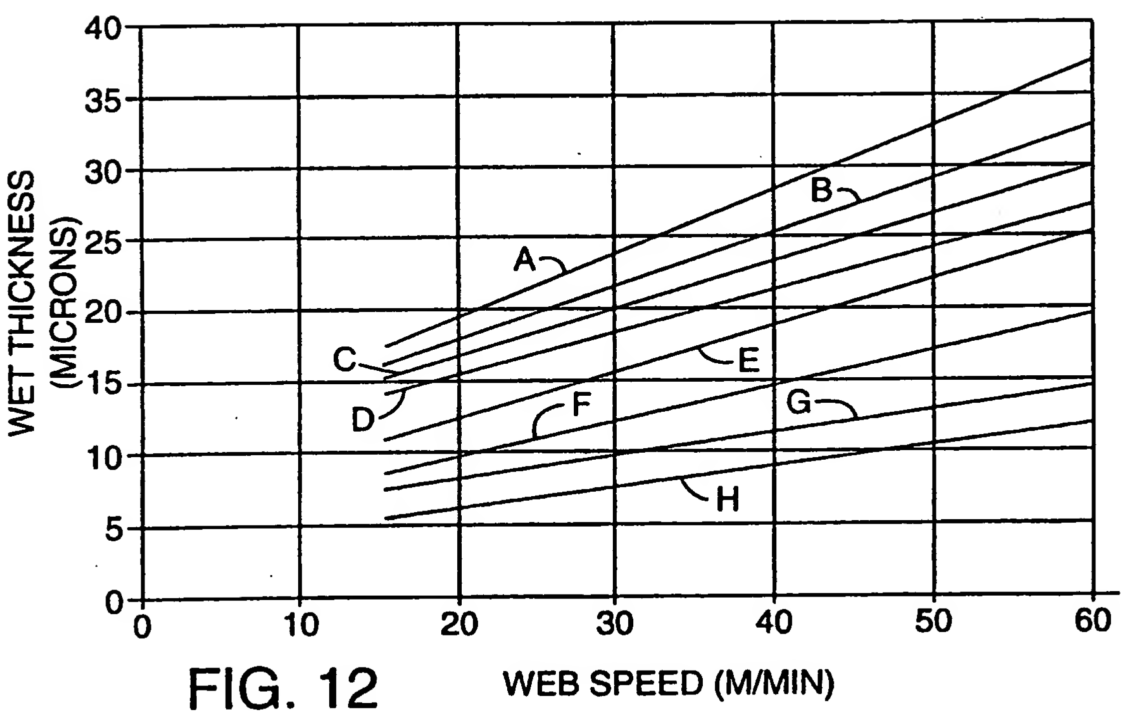
WET THICKNESS (MICRONS)
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
A
B
C
D
E
F
G
H
WEB SPEED (M/MIN)

FIG. 12

VIS (CPS)	Vw (M/MIN)		Tw (MICRONS)		CTG GAP (MM)		VAC (MM H20)	
	PRIOR	NEW	PRIOR	NEW	PRIOR	NEW	PRIOR	NEW
37.6	9.1		22.2		0.076		190.5	
37.6		18.3		15.4		0.076		96.5
37.6		24.4		15.4		0.076		101.6
39.5	18.3	18.3	42	31	0.076	0.124	132.1	43.2
39.5	36.6	36.6	47.2	31	0.076	0.099	165.1	93.9
47	30.5	30.5	45.7	45.7	0.102	0.254	109.2	5.1
131.4	18.3	18.3	62	62	0.102	0.264	66	0
131.4		38.1		62		0.305		0
140	12.2	12.2	33.8	23.1	0.076	0.081	101.6	104.1
158	9.1		46.5		0.076		76.2	
158		15.2		23.2		0.076		167.6
600	15.2	15.2	177.3	177.3	0.254	0.432	0	0
600	24.4	24.4	177.3	177.3	0.254	0.305	25.4	0

FIG. 13

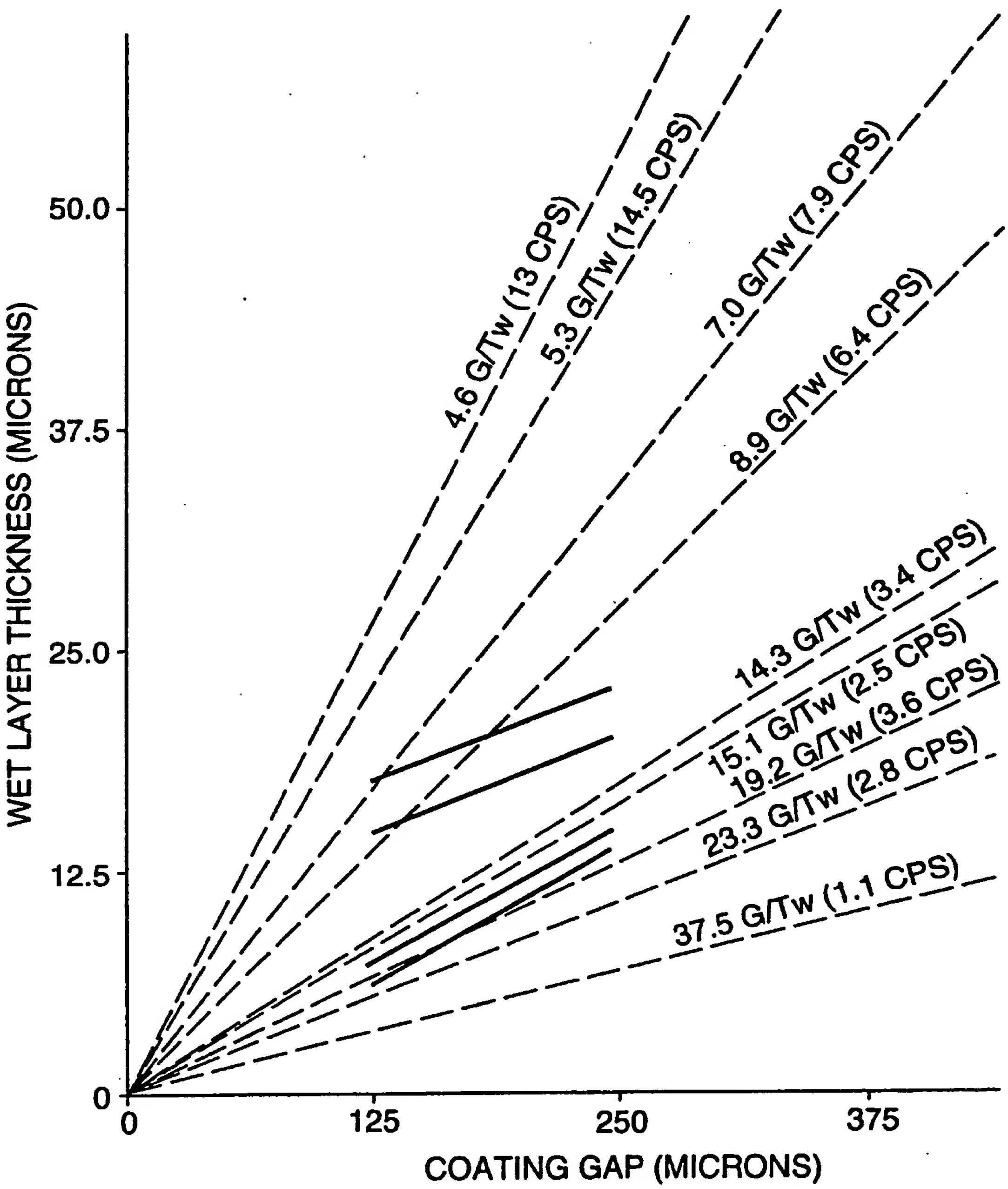
WET LAYER THICKNESS (MICRONS)
50.0
37.5
25.0
12.5
0
0
125
250
375
COATING GAP (MICRONS)
4.6 G/Tw (13 CPS)
5.3 G/Tw (14.5 CPS)
7.0 G/Tw (7.9 CPS)
8.9 G/Tw (6.4 CPS)
14.3 G/Tw (3.4 CPS)
15.1 G/Tw (2.5 CPS)
19.2 G/Tw (3.6 CPS)
23.3 G/Tw (2.8 CPS)
37.5 G/Tw (1.1 CPS)

FIG. 14

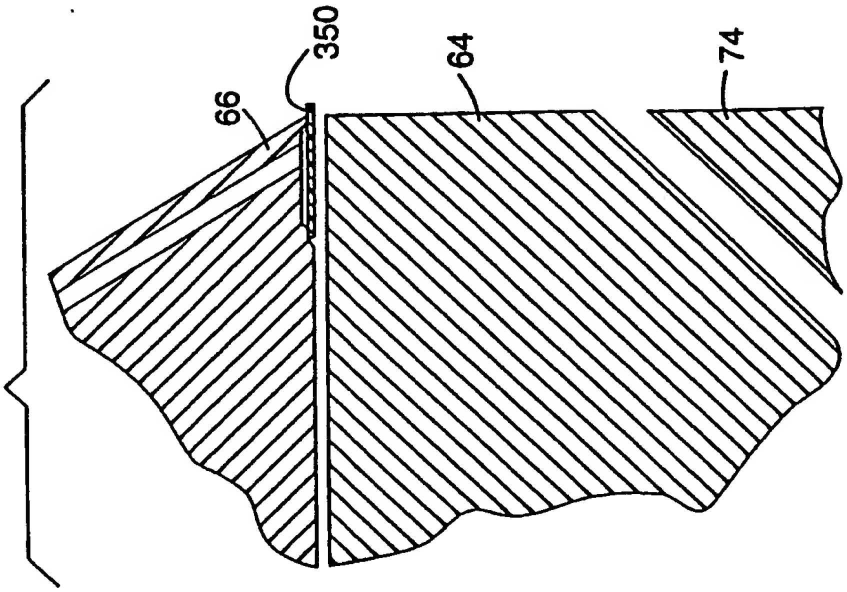

FIG. 16

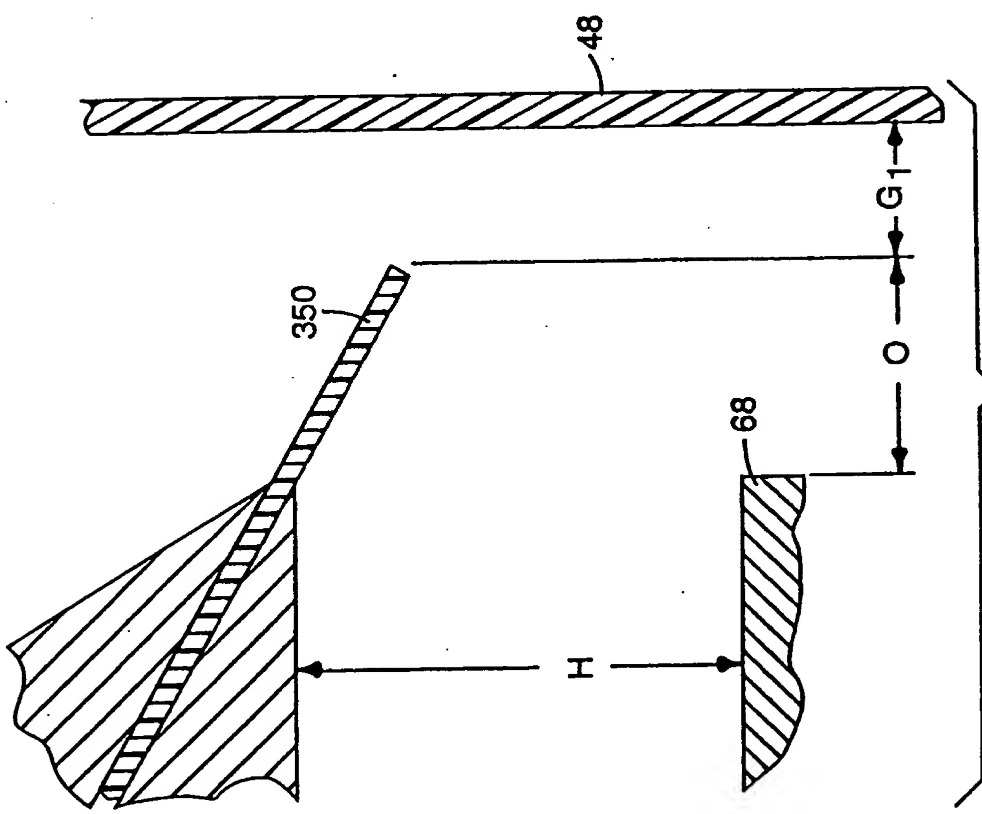

FIG. 15

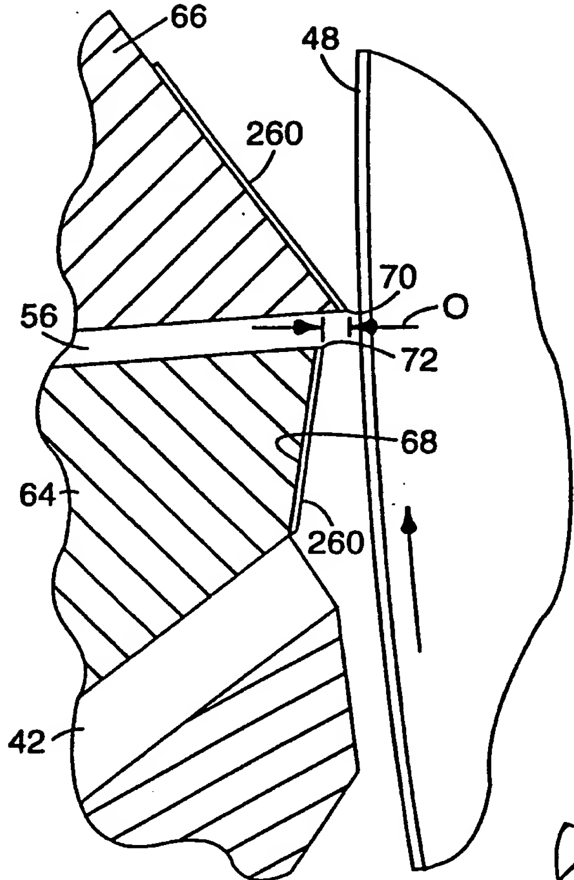

FIG. 17

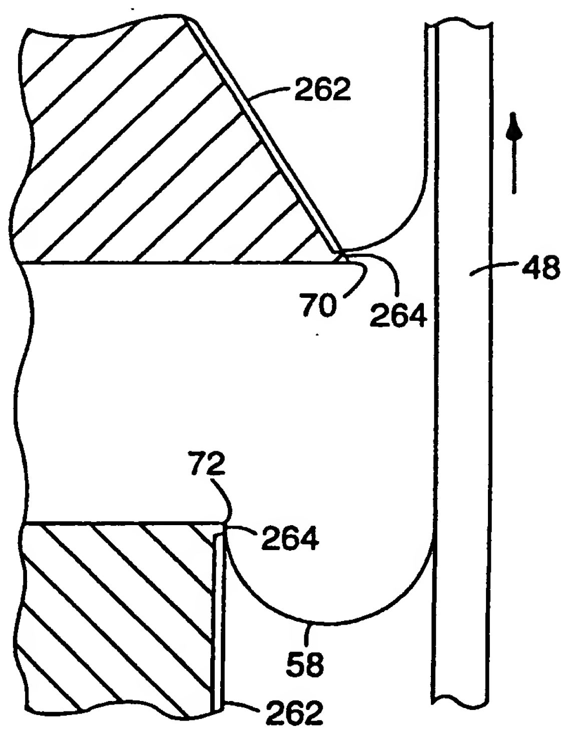

FIG. 18

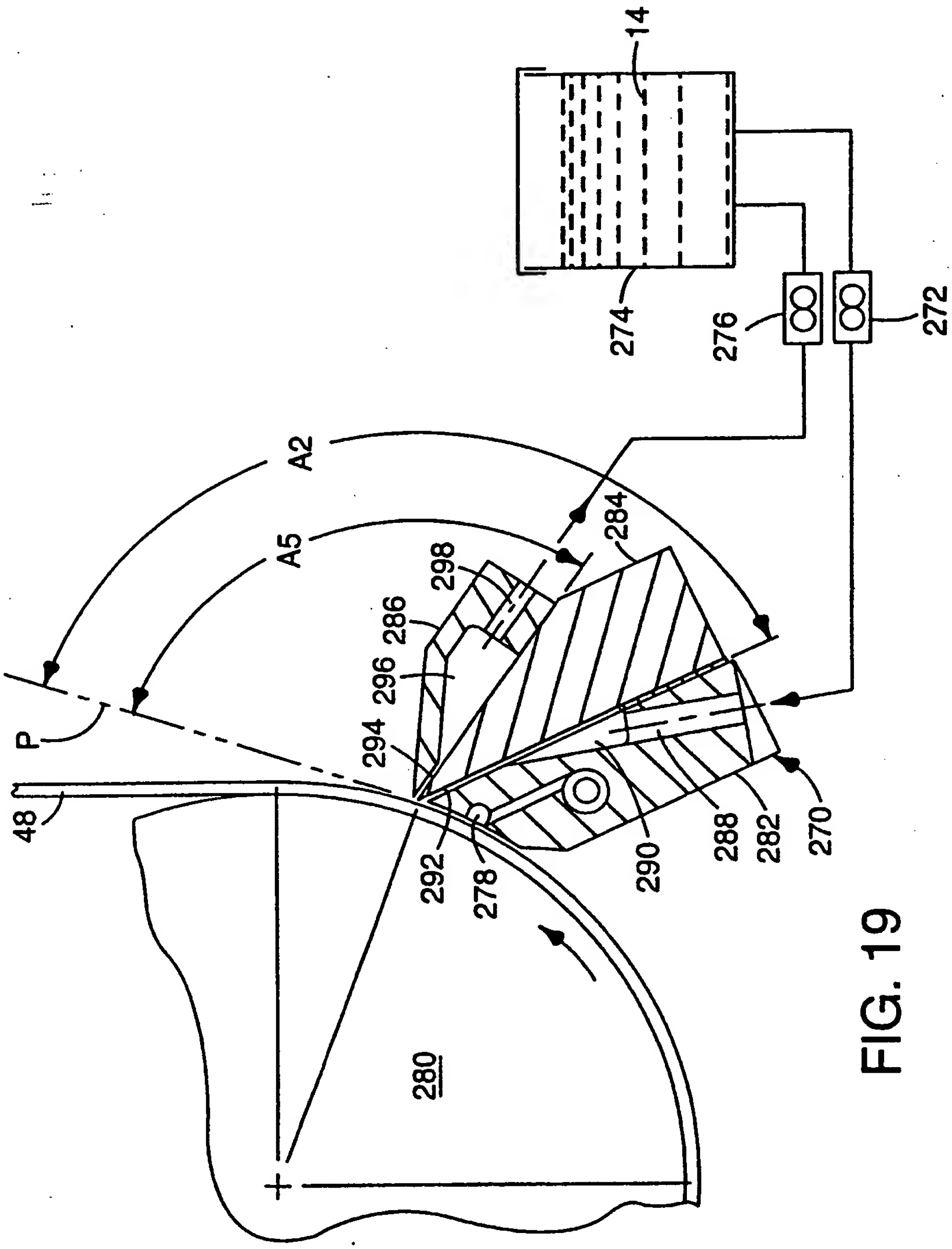
14
274
276
272
A2
A5
284
298
286
296
294
P
48
292
278
290
288
282
270
280

FIG. 19

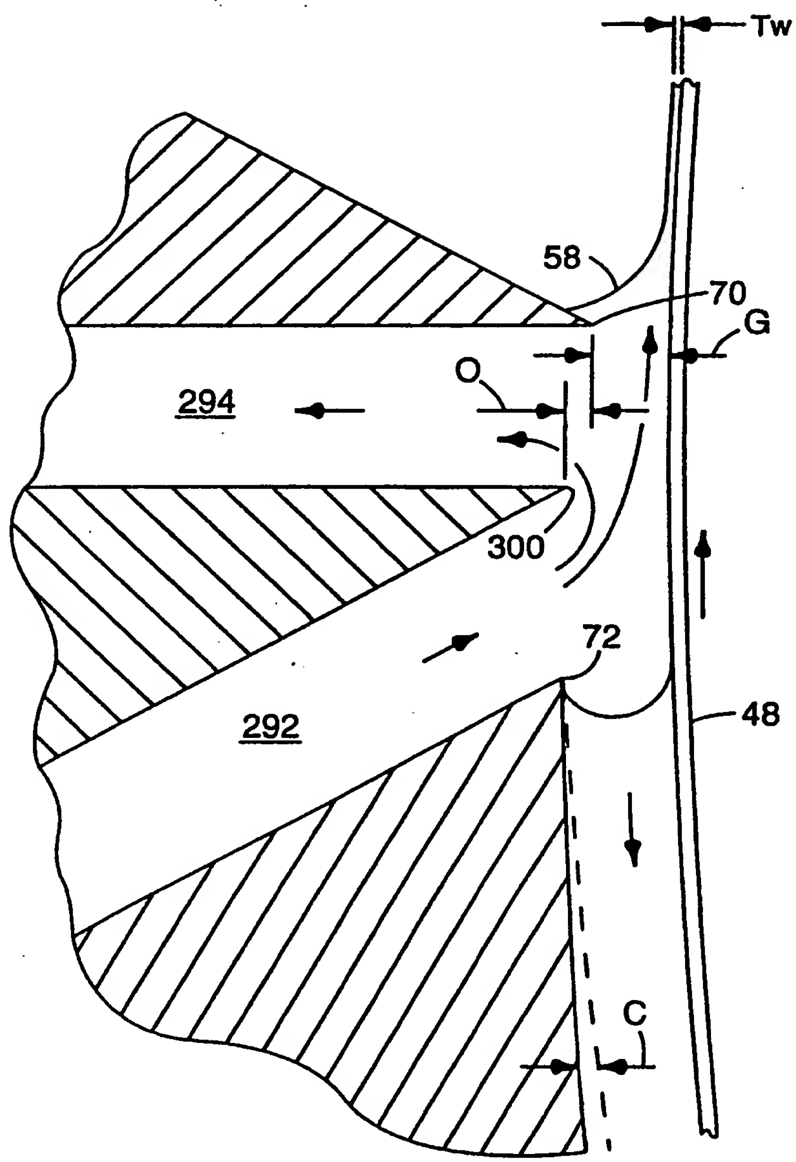

FIG. 20

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 95/03312

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B05C5/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B05C G03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB-A-2 120 132 (KONISHIROKU) 30 November 1983	1,2,6, 13,17
A	see page 2, line 48 - page 3, line 95; figure 3	3-5,11
X	FR-A-2 375 914 (INVENTING S.A.) 28 July 1978	1,6,9, 13,17
A	see page 16, line 1 - line 24; figure 5	10
X	DE-A-37 23 149 (FUJI) 21 January 1988	1,2,13
A	see the whole document	4,5,14
P,X	EP-A-0 609 768 (HOECHST) 10 August 1994 see abstract; figures 1,2	1,2,6,9, 13,17

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

3

Date of the actual completion of the international search	Date of mailing of the international search report
12 September 1995	09.10.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Guastavino, L

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Inte[...]nal Application No
PCT/US 95/03312

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP-A-0 466 420 (ISHIKAWAJIMA-HARIMA) 15 January 1992 see abstract; figure 4A ---	1
X	EP-A-0 196 029 (UNION CARBIDE CORPORATION) 1 October 1986 see claims 1,3,4; figures 2-7 ---	1,7,13, 16
A	EP-A-0 484 738 (PAGENDARM) 13 May 1992 see abstract; figure 1 ---	5
A	EP-A-0 552 653 (DU PONT DE NEMOURS) 28 July 1993 see claims 7,8 ---	12
A	US,A,3 413 143 (E. CAMERON ET AL) 26 November 1968 see column 2, line 29 - line 36; figure 3 see column 2, line 68 - line 70 ---	18,21
A	DE,U,91 12 589 (VOITH) 12 December 1991 see page 5, paragraph 2; figure 1 -----	18,21

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 95/03312

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
GB-A-2120132	30-11-83	JP-C-	1496983	16-05-89
		JP-A-	58202075	25-11-83
		JP-B-	63045263	08-09-88
		DE-A-	3317998	24-11-83
		US-A-	4748057	31-05-88
FR-A-2375914	28-07-78	SE-B-	416970	16-02-81
		BE-A-	862539	14-04-78
		CH-A-	644284	31-07-84
		CH-A-	670542	30-06-89
		DE-A-	2758649	13-07-78
		GB-A-	1595214	12-08-81
		JP-A-	53106895	18-09-78
		JP-B-	61020673	23-05-86
		SE-A-	7700045	04-07-78
		US-A-	4158076	12-06-79
DE-A-3723149	21-01-88	JP-B-	6077711	05-10-94
		JP-A-	63020069	27-01-88
		US-A-	4907530	13-03-90
EP-A-609768	10-08-94	DE-A-	4303357	11-08-94
		JP-A-	6292853	21-10-94
EP-A-466420	15-01-92	JP-A-	4071659	06-03-92
		CA-A-	2044449	11-01-92
		DE-D-	69109556	14-06-95
		ES-T-	2071923	01-07-95
		US-A-	5186753	16-02-93
EP-A-196029	01-10-86	US-A-	4912948	03-04-90
		JP-A-	61220759	01-10-86
EP-A-484738	13-05-92	DE-A-	4035091	07-05-92
EP-A-552653	28-07-93	US-A-	5380365	10-01-95
		JP-A-	5261332	12-10-93
US-A-3413143	26-11-68	BE-A-	656944	01-04-65
		CH-A-	442087	

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/US 95/03312

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-3413143		DE-A- 1577798	02-01-70
		GB-A- 1048829	
		NL-A- 6414375	11-06-65
DE-U-9112589	12-12-91	NONE	

Form PCT/ISA/210 (patent family annex) (July 1992)

Int. ...tional application No.

PCT/US 95/03312

INTERNATIONAL SEARCH REPORT

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1.claims1-7:die coating apparatus with downstream sharp edge,and associated method.
2.claims18-23:multi-layer die with an upstream land,a middle lip and downstream lip as sharp edges and associated method

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.